TECHNICAL ASPECTS OF SPATIAL DATA PREPARATION WITHIN THE MARINE ADMINISTRATION SYSTEM AS SUPPORT FOR THE SUSTAINABLE DEVELOPMENT OF THE BLUE ECONOMY

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Abstract: *Establishing a Marine Administration System (MAS) is crucial for countries bordering seas and oceans, particularly within the framework of the United Nations Convention on the Law of the Sea (UNCLOS). This involves delineating marine zones and providing comprehensive information on property rights in territorial seas, contiguous zones, and exclusive economic zones, which is vital for safeguarding sovereign rights.*

In Romania, the transposition of Directive 2014/89/EU and the adoption of Government Ordinance No. 18/2016 on maritime spatial planning, along with Emergency Ordinance No. 97/2023 for the Maritime Spatial Plan, are pivotal for promoting sustainable development within the Blue Economy. This study addresses the technical aspects of spatial data preparation essential for implementing a MAS, focusing on the generation of a Digital Elevation Model (DEM) for seabed topography, integrated with terrestrial topography.

A significant aspect highlighted is the need to extend the quasigeoid model for Romania to include maritime areas. This extended quasigeoid facilitates the transformation of altitudes and depths derived from GNSS and bathymetric measurements, which are traditionally referenced to local surfaces specific to hydrographic measurements. By eliminating the need for direct tide measurements, the study underscores the importance of accessing recent topographic and bathymetric data based on a precise datum.

Additionally, the research outlines a workflow utilized in other countries for generating DEMs using GNSS and bathymetric measurements, employing ArcMap and ArcScene from the ArcGIS suite, and illustrates the 3D visualization of marine parcels. The development of a Marine Spatial Data Infrastructure (MSDI) based on the DEM and an extended quasigeoid model for Romania in the Black Sea area will ensure that marine spatial data is accessible for state authorities. This infrastructure aims to facilitate data comparison and exchange, integrating with initiatives such as Marine Knowledge 2020 and the Inspire Directive (2007/2/EC) and Directive 2014/89/EU, thereby supporting the effective management of coastal and marine zones.

Keywords*: Marine Administration System; Marine Spatial Data Infrastructure; Marine Spatial Planning; UNCLOS; Digital Elevation Model; quasigeoid; marine parcel*

1. Introduction

The international workshop on Administering the Marine Environment, held in Malaysia in 2004, proposed adopting the term “Marine Administration System” as an analogy to the “Land Administration System.” This term encompasses the administration of rights, restrictions, and responsibilities in the marine environment, with a spatial dimension facilitated by Marine Spatial Data Infrastructure (MSDI).

Countries bordering seas and oceans face the complex challenge of managing vast marine spaces, which requires effective governance. Marine Administration Systems play a crucial role in this process by helping to balance the sustainable use and protection of marine resources. These systems are underpinned by various practices, including Marine Spatial Planning (MSP), which integrates social, economic, and environmental goals for the usage of marine spaces. Additionally, the Marine Cadastre (MC) provides clear delineation of property rights and boundaries in the marine environment, while the MSDI supplies essential geospatial data that promotes efficient decision-making across marine-related sectors.

A foundational framework in these efforts is the United Nations Convention on the Law of the Sea (UNCLOS), which was signed in Montego Bay, Jamaica, in 1982 and came into effect on 16 November 1994. UNCLOS defines the rights and responsibilities of nations regarding their use of the world's oceans and seas, establishing guidelines for businesses, environmental stewardship, and the management of marine natural resources. The Convention introduced numerous provisions, including the delineation of marine areas and their respective limits, navigation rights, archipelagic status, transit regimes, exclusive economic zones, continental shelf jurisdiction, deep seabed mining, exploitation regimes, protection of the marine environment, scientific research, and dispute resolution mechanisms. Importantly, UNCLOS influences how offshore parcels are defined, affecting not only how a nation establishes its limits but also how it specifies the depths or layers at which rights begin and cease (Cockburn, Nichols et al. 2003).

This systematic approach to marine governance is particularly relevant to the Blue Economy—a sustainable economic model that harnesses the potential of oceans while ensuring the protection of marine ecosystems. Effective Marine Administration Systems are critical for sustainable development, as they optimize resource use, promote conservation, and foster innovation across marine sectors such as fisheries, tourism, and renewable energy.

In the context of Romania, significant steps have been taken to align with European Union maritime policy. The transposition of EU Directive 2014/89/EU into national law established the foundation for Romania’s marine spatial planning. This initiative was further strengthened by Ordinance No. 18/2016, which laid out the framework for maritime spatial planning, and more recently by Emergency Ordinance No. 97/2023, which introduced Romania’s Maritime Spatial Plan, setting strategic goals for sustainable maritime development.

2. Marine Data Model and Standard Criteria for the Marine Administration System: Integrating 3D/4D Marine Parcel Concepts

The **United Nations Convention on the Law of the Sea (UNCLOS)** has a significant impact on defining offshore parcels. Firstly, UNCLOS specifies how the maritime limits of a ratifying nation are to be delineated. For Romania, the area of interest for the maritime spatial development plan encompasses the Romanian sector of the Black Sea. **Law No. 17 of August 7, 1990** regulates the legal status of inland maritime waters, the territorial sea, the contiguous zone, and the Exclusive Economic Zone (EEZ) in accordance with the provisions of UNCLOS, which Romania ratified through **Law No. 110/1996** (see Fig. 1).

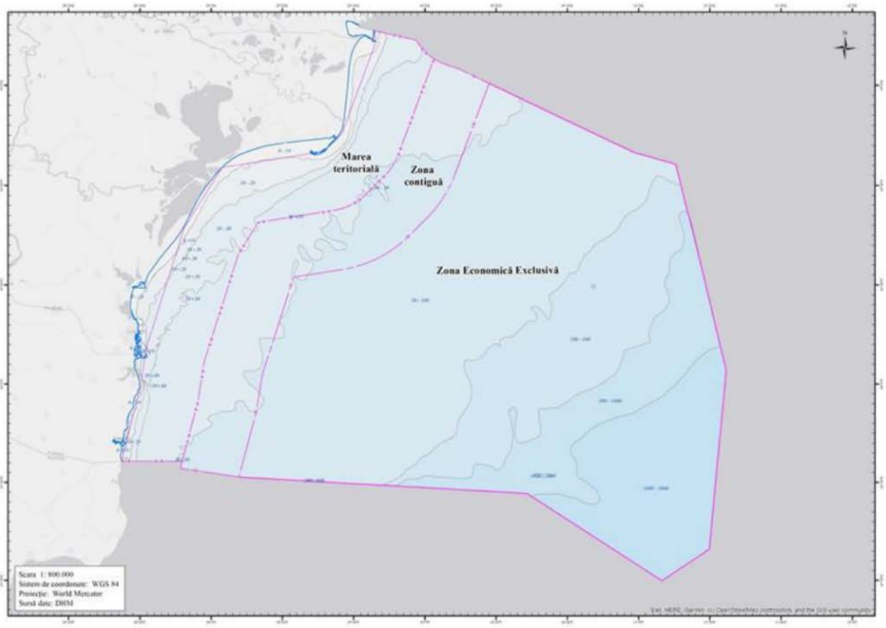

Figure 1. The limits of the maritime spaces of Romania
Data Source: Maritime Hydrographic Directorate, 2022

Romania's territorial sea includes a strip of water adjacent to the shore, as well as inland maritime waters, with a width of 12 nautical miles (approximately 22.2 km) measured from the baselines. The contiguous zone extends offshore to a distance of 24 nautical miles from the established baselines, adjacent to the territorial sea. The Exclusive Economic Zone encompasses the marine space beyond the territorial sea, where Romania exercises sovereign rights and jurisdiction over natural resources found in the seabed, its subsoil, and the water column above, as well as activities related to exploration, exploitation, environmental protection, conservation, and management. The EEZ covers an area of approximately 25,000 km², with a maximum width of 200 nautical miles measured from the baselines.

Secondly, UNCLOS specifies the depths or layers at which a ratifying nation's rights in ocean space begin and cease. This is illustrated in **Figure 2**, which shows that while a nation has rights over the airspace within the territorial sea, its rights concerning the continental shelf only commence at the seafloor.

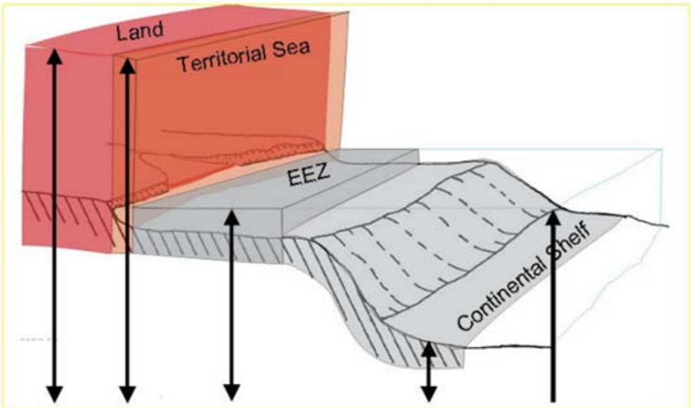

Figure 2. Black arrows illustrating the vertical extent of a nation's sovereign rights in the specified UNCLOS zones. The right-hand arrow points to the water surface
Source: (Cockburn, Nichols et al. 2003)

In summary, UNCLOS influences both the vertical and horizontal dimensions of a nation’s marine parcel. The concept of cadastral depth is more complex in the marine environment than on land, as land-based cadastral systems were developed in contexts where nations held absolute jurisdiction. Additionally, evidentiary tools utilized under UNCLOS for determining national boundaries differ from traditional methods.

The complex nature of marine environments necessitates the development of advanced data models for marine parcel systems. These systems must account for the unique characteristics of marine spaces, including their 3D/4D aspects, and incorporate environmental, legal, and institutional elements. A marine parcel model seeks to accurately represent marine parcels by considering the sea surface, water column, seabed, and subsurface. These models define the rights, responsibilities, and restrictions associated with various stakeholders, whether they are formal, informal, governmental, or private (see Fig. 3).

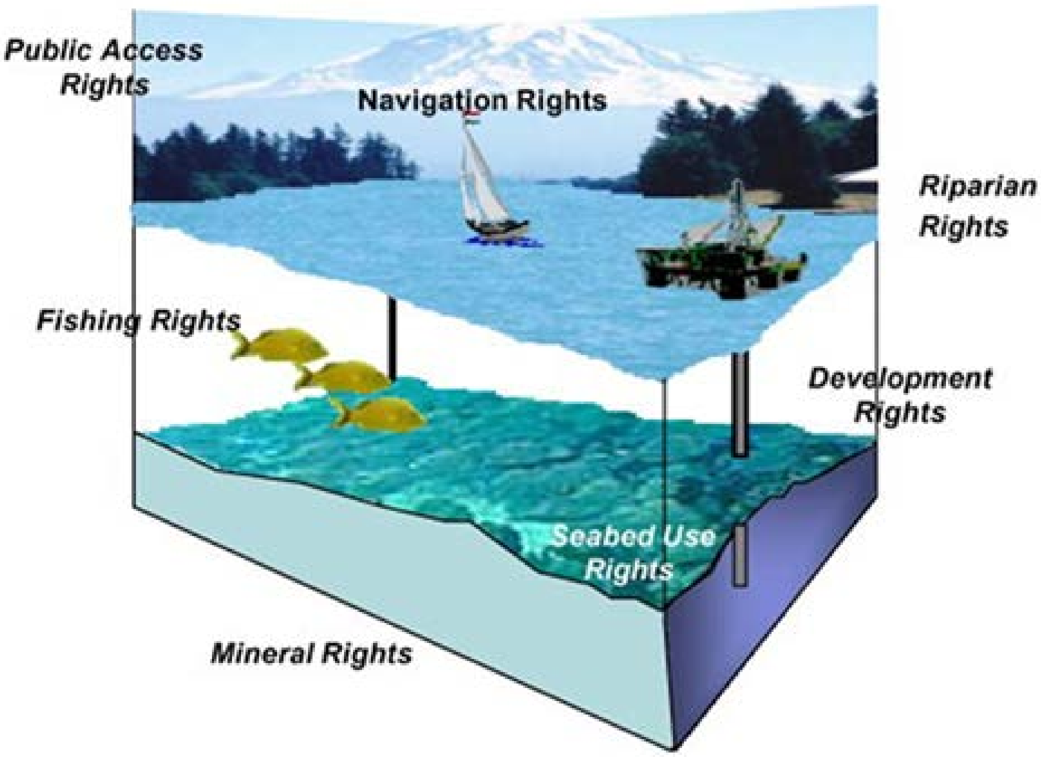

Figure 3. The marine parcel
Source: (Adapted from Sutherland and Nichols, 2002)

Marine parcels must capture not only horizontal (2D) boundaries, as is common in land cadastres, but also vertical (3D) and, at times, temporal (4D) dimensions. Rights and responsibilities can apply at different depths, extending from the surface to the seabed, and may vary over time. For instance, the regulation of certain underwater resources may change seasonally. This dynamic characteristic differentiates marine cadastres from land cadastres, which are primarily two-dimensional and tend to be less fluid over time.

Marine parcels necessitate the integration of 3D/4D spatial data to effectively manage overlapping rights and responsibilities that exist in vertical space—both above and below the water's surface. In contrast, land cadastres traditionally focus on surface-level parcels, with less emphasis on vertical layering. This distinction has been highlighted by experts such as Collier, Leahy, and Williamson, who emphasize the need for more advanced modeling techniques in marine contexts (see Table 1).

Table 1. Differences between Land Parcels and Marine Parcels
[Modified by authors based on Collier, Leahy, & Williamson (2001a, 2001b); Binns, Rajabifard, Collier, & Williamson (2004)]

Land Parcel	Marine Parcel
Rights of full ownership or exclusive use.	Virtually no rights of full ownership or exclusive use of marine space.
Standard land demarcation techniques apply; boundaries are delimited, demarcated, and have physical evidence of offshore boundaries.	Standard land demarcation techniques are not applicable; marine boundaries are delimited but not demarcated, lacking physical evidence of offshore boundaries.
Overlapping rights in a single area are uncommon.	Multiple (overlapping) rights in a single area are common.
Classical 2D simplifications are adequate.	The marine environment is three-dimensional; classical 2D simplifications are insufficient.
Rights do not vary with time.	Rights can vary over time, introducing a fourth dimension into the spatial data.
Baselines for land boundaries are non-transferable.	Baselines for marine boundaries are transferable.

In developing marine parcels, applying international standards is critical for ensuring interoperability and consistency across jurisdictions. Several standards are currently being adapted from land administration to marine contexts, including:

- **LADM (Land Administration Domain Model)**: LADM provides a conceptual framework supporting the representation of relationships between people and land, encompassing rights, responsibilities, and restrictions. This framework can be extended to marine parcels, enhancing the management of marine space.
- **S-100 and S-121 (International Hydrographic Organization Standards)**: S-100 serves as a universal data framework for marine geospatial information, while S-121 specifically addresses the management of maritime boundaries and related rights, aiding the administration of legal regimes in marine environments.
- **INSPIRE (Infrastructure for Spatial Information in Europe)**: INSPIRE facilitates spatial data interoperability across European nations. Although originally focused on land administration, its principles are being applied to marine spatial data infrastructures to ensure seamless integration of marine and terrestrial data.

In conclusion, the marine parcel is a critical component supporting the sustainable development of the Blue Economy. By incorporating 3D/4D data models and adhering to international standards, the Marine Administration System can efficiently manage marine spaces, ensuring that diverse stakeholder rights are respected and sustainable development goals are met.

3. The Role Of Digital Elevation Models and Seamless Vertical Datums in Supporting the Marine Administration System in Romania

Digital Elevation Models (DEMs) offer a 3D representation of terrain, which is crucial for various marine-related applications such as marine parcel development, coastal management, and flood monitoring. However, in marine environments, the challenge lies in harmonizing two distinct vertical reference systems: one used for land elevations and another for seabed depths. This discrepancy at the land-sea interface can affect the accuracy of spatial data, leading to inconsistencies in coastal and marine projects.

Traditionally, seabed depth is referenced to a **Chart Datum (CD)**, while land elevation uses a **terrestrial vertical datum**. This creates mismatches, as chart datums are not uniform, varying not only between regions and countries but also over time. The **Chart Datum** is typically based on local tidal phases and may differ from location to location. Commonly used chart datums include **Lowest Astronomical Tide (LAT)** and **Mean Lower Low Water (MLLW)**. CD is usually derived from tidal observations and lacks the seamless nature needed for integrating marine and terrestrial datasets.

As the CD varies with location and is established based on discrete water level measurements, predicting sea level changes over large distances becomes uncertain. This uncertainty, which can reach several decimeters, can impact the accuracy of seabed depth data and nautical charts. For reliable results, especially in GNSS-based applications, the chart datum must be well-defined and compatible with GNSS positioning.

3.1. The Solution: Seamless Geoid-based Vertical Datums

To overcome these challenges, a seamless reference surface such as the **geoid** or **quasigeoid** is essential. These surfaces align with **Mean Sea Level (MSL)** and provide a unified reference system for both land and sea, eliminating the need for separate vertical datums. The seamless geoid-based vertical datum facilitates smooth transitions between terrestrial and marine datasets, ensuring better integration and consistency.

With modern **Global Navigation Satellite System (GNSS)** technology, it is possible to reference both land and seabed data to a single geoid or quasigeoid model. This approach enhances the accuracy and consistency of spatial data and also reduces reliance on traditional tide gauges. Bathymetric surveys can now be performed without direct tide measurements, using GNSS data to determine normal altitudes based on a qusigeoid model. Figure 4 illustrates the translation of GNSS leveling over a water body.

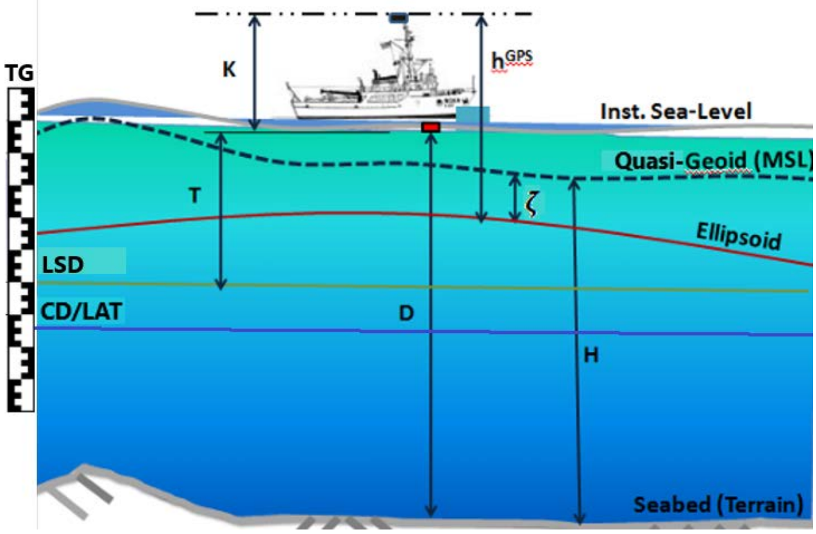

Figure 4. Surveing formulae for traditional and quasi-geoid based seamless vertical datum
Source: (Adapted from Mohd Amsyar Bin Abdullah, Abdullah Hisam Omar, 2011)

In Figure 4 the following notations were made:
H – normal height;
h^{GPS} – ellipsoid height;
ζ - altitude anomaly;
D - depth measured by echo sounder from transducer to seabed;

K - offset from antenna of receiver to transducer
T - tide reading reduced to LSD
To better understand the integration of GNSS-derived data with traditional marine surveying techniques, the following formulas apply:

$$H_{reduced} = D - T \quad (1)$$

$$H = (D + K) - h + \zeta \quad (2)$$

$$H_{reduced} \simeq H \quad (3)$$

By these equations, the normal height **H** can be reduced to the seabed, allowing the seabed topography to be generated relative to the quasigeoid as the vertical datum.

3.2. Applications of Seamless Geoid-based Datums

1) **Hydrographic Surveying**: The application of a geoid or quasigeoid model in GNSS-based height measurements enables hydrographic surveys without the need for direct tidal measurements. This improves the efficiency of seabed mapping and creates consistent 3D models for marine and coastal management.
2) **Marine Parcels**: Seamless DEMs allow for accurate legal delimitation of marine boundaries, crucial for governance in the **Blue Economy**. Clear definitions of boundaries are essential for maritime activities, such as resource management, conservation, and navigation.
3) **Coastal Zone Monitoring and Management**: The seamless vertical datum aids in integrating land and marine data, which is vital for coastal management, flood monitoring, and storm surge modeling.
4) **Shoreline Monitoring**: Seamless datums also enhance the precision of shoreline monitoring and boundary delineation, essential for legal and environmental purposes, including determining baselines from low-water features.

By using a unified geoid-based vertical datum, it is possible to generate accurate **Triangulated Irregular Network (TIN)** models and DEMs that represent both the seabed and terrestrial elevations in a 3D environment. These models are essential for marine parcel management and support the sustainable development of the Blue Economy by eliminating inconsistencies at the land-sea interface.

3.3. Extending the Quasigeoid for Romania

To extend the quasigeoid for Romania in the Black Sea area, an iterative process of data acquisition and improvement can be initiated. Each stage of this process builds on the previous stage's quasigeoid model. Data collection methods include:

- **Terrestrial gravity measurements**, already in use for Romania's quasigeoid realization project;
- **Shipborne gravity measurements**, using GNSS receivers, inertial measurement units (IMU), and marine gravimeters;
- **Airborne gravity surveys**, integrating data from the Black Sea, Dobrogea region, and Danube Delta;
- **Precise leveling and GNSS measurements**.

An example of GNSS-based measurements carried out in Romania is shown in Figure 5.

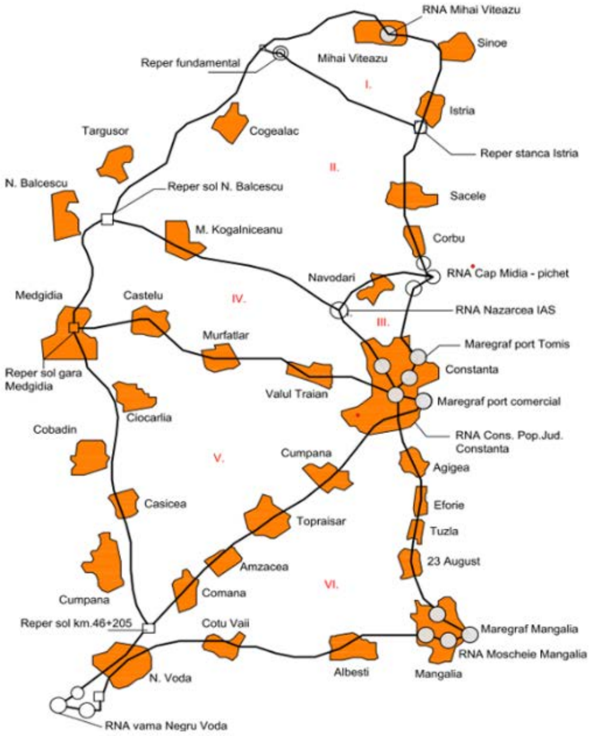

Figure 5. The sketch of the polygons connecting the fundamental landmark to the high-precision leveling network and tide gauges
Source: (Marius Dorin ANTON, Radu CRIȘAN, Vasile NACU , Ioan STOIAN, June 2016)

The new quasigeoid can be estimated using the **Remove-Compute-Restore** method. In step 'remove', represented by relation (4), the long-wavelength gravitational effects of a global geopotential model Δg_{GGM}, and the high-frequency local terrain effects Δg_{RTM} are removed from the free air anomalies Δg_{FA}, resulting in smooth residual gravity anomalies Δg_{res}.

$$\Delta g_{res} = \Delta g_{FA} - \Delta g_{GGM} - \Delta g_{RTM} \qquad (4)$$

The effects of the terrain Δg_{RTM} are computed using the RTM approach (Forsberg, 1984) where only the topographic irregularities relative to a smooth mean height surface are taken into account.
The smooth surface can be constructed by low-pass filtering of the detailed DTM to transform it into a coarse and smooth topography grid. The RTM is given by (Forsberg 1984):

$$\Delta g_{RTM} = 2\pi G\rho\left(H - H_{ref}\right) - C_T \qquad (5)$$

where H_{ref} is the height of the smooth reference surface, and H is the height of the computation point respectively, and C_T is the classical terrain correction.

In the 'compute' step, the Stokes integral is applied to the residual gravity anomalies Δg_{res} to generate the residual height anomaly $\zeta_{\Delta g_{res}}$using the Fast Fourier Transform - FFT (Kaminskis, Forsberg, 1996).

In the 'restore' step, the components removed in the first step are restored to the residual height anomaly $\zeta_{\Delta g_{res}}$, in the form of the height anomaly ζ_{GGM} computed from a global geopotential model and the height anomaly ζ_{RTM} as a result of the effects of the terrain. This process is presented according to equation (8).

$$\zeta = \zeta_{\Delta g_{rez}} + \zeta_{GGM} + \zeta_{RTM} \qquad (6)$$

Traditionally, geoid/quasigeoid models have been validated using GNSS-levelling benchmarks (precise levelling and GNSS) exclusively on land. Since such benchmarks cannot be established offshore, the evaluation of marine areas in quasigeoid models requires a different approach.

In the iterative process of generating the quasigeoid, gravimetric height anomalies can be verified and corrected using the method described by Nordman et al. (2018). In this method, GNSS-IMU observations are combined with sea surface models (such as tide gauge surfaces and physical forecast models) to validate existing quasigeoid models for the area. Additionally, a new quasigeoid model is calculated using marine gravity data from the current campaign, and this new model is validated as well (see Figure 6).

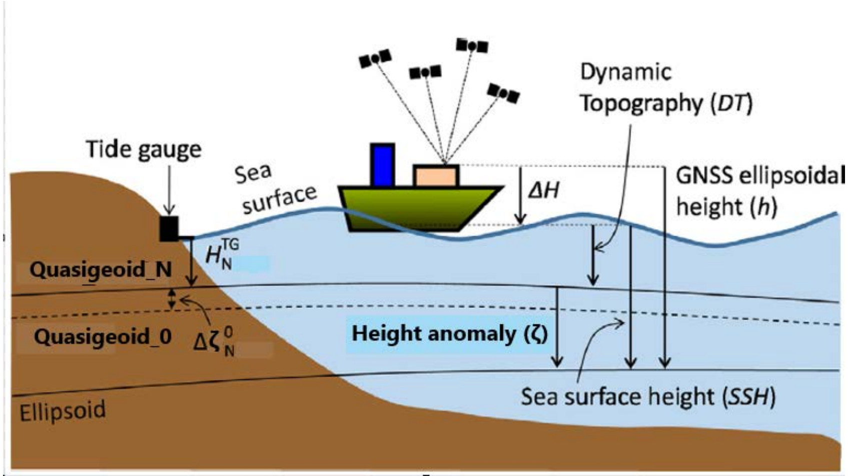

Figure 6. Relations between the different heights and surfaces
Source: (Adapted from Timo Saari, Mirjam Bilker-Koivula, Hannu Koivula, Maaria Nordman, Pasi Häkli & Sonja Lahtinen, Mar 2021)

To obtain the height anomaly, ζ, from GNSS data, the ellipsoidal height, h, must first be reduced using precise tide measurements, ΔH, to account for the sea level at the exact time of measurement, resulting in the sea surface height (SSH):

$$h_{SSH}=h-\Delta H \quad (7)$$

Next, the dynamic topography (DT), which represents the prevalent sea surface topography, is modeled and subtracted from the SSH. The resulting height anomaly provides the distance between the mathematical ellipsoid and the physical quasigeoid surface:

$$\zeta = h_{SSH}-DT \quad (8)$$

Figure 6 illustrates the relationships between the reference heights and surfaces. **'Quasigeoid_0'** refers to the geopotential surface of the quasigeoid when it is not aligned with a national height system, whereas **'Quasigeoid_N'** refers to the geoid aligned with the **N** height system.

The offset between the aligned and non-aligned quasigeoid models is represented by $\Delta\zeta_N^0$, and H_N^{TG} denotes the sea level measured by a tide gauge within the N height system.

The resulting height anomalies, in desired reference frames, are used for validating the previously existing and the new quasigeoid models.

4. Data Processing For DEM Generation and Visualizing 3D Marine Spatial Data

The data necessary for generating DEMs in the Black Sea area can be acquired through a combination of bathymetric measurements. This involves using a dual-beam acoustic echo sounder for depth measurement, a kinematic GNSS antenna mounted on the survey vessel, and both temporary and permanent GNSS base stations strategically installed around the research areas. These systems provide three-dimensional positioning with centimeter-level accuracy, alongside a data acquisition system to record depth and position data.

Accurate sensor offsets between the probe transducer and the positioning antenna must be precisely measured and applied within the data acquisition system. The coordinates of the topographical points will be collected using the **Real-Time Kinematic (RTK)** GNSS technique, ensuring high accuracy.

The bathymetric data, typically provided in Excel format, includes point coordinates (latitude, longitude, and height), depth measurements reduced to the Chart Datum (CD), depth converted to the Land Survey Datum (LSD), derived from the nearest Temporary Benchmark (TBM) to the jetty, and the offset value between the GNSS antenna and the transducer.

4.1. Generating the DEM

To generate the DEM, it is essential first to create a **Triangulated Irregular Network (TIN)** using the collected data, which consists of point coordinates and measured heights. The seabed topography can be visualized in 3D by generating the DEM. The creation of TIN and DEM can be accomplished using **ArcGIS** software (specifically **ArcMap** and **ArcScene**) to develop the seabed topography for further analysis.

The main steps for generating seamless seabed and land topography include:

1) Processing data collected through bathymetric and GNSS measurements.
2) Generating a height grid and exporting it to a .dxf file.
3) Importing the height grid into ArcMap.
4) Creating a TIN from the feature class and adding contour lines.
5) Converting the TIN to a raster map to generate the DEM.
6) Importing both the TIN and DEM into ArcScene to create a 3D model.
7) Adjusting the vertical exaggeration and base heights to enhance the visualization of the 3D seabed topography.

This seamless topographical production, based on a seamless vertical datum (quasigeoid), can be applied in developing a **Marine Spatial Data Infrastructure (MSDI)**. This system stores all cadastral information and spatial data related to specific marine and coastal areas, allowing for 3D visualization that aids in the accurate assimilation of underwater boundary marks.

Figure 7 below illustrates a 3D view of a marine lot, demonstrating this integration.

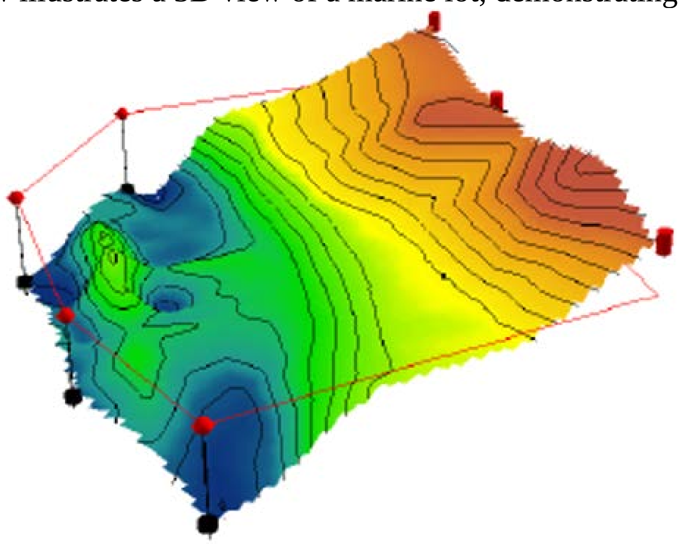

Figure 7. 3D view of a marine lot
Source: (Mohd Amsyar Bin Abdullah, Abdullah Hisam Omar, 2011)

To facilitate the implementation of stratum titles in a marine parcel environment, it is necessary to form a 3D model of the seamless terrain. This model is essential for visualizing marine lots and land parcels, which cannot be effectively represented in 2D. Figure 8 below shows the marine stratum parcels defined by predetermined depth intervals.

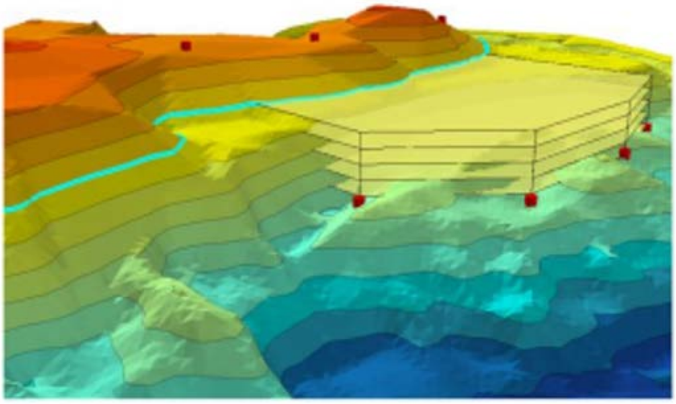

Figure 8. Marine stratum parcels defined by predetermined depth interval
Source: (Mohd Amsyar Bin Abdullah, Abdullah Hisam Omar, 2011)

Each owner of a marine stratum title is responsible for the rights, restrictions, and obligations associated with their designated area (parcel), which is based on specific predetermined depths. By leveraging the DEM and the quasigeoid model for Romania, extended into the Black Sea area, a comprehensive Marine Spatial Data Infrastructure (MSDI) can be developed. This ensures that marine spatial data is readily accessible for comparison and exchange among state authorities for various purposes. This infrastructure aligns with the principles of **Marine Knowledge 2020** and the **INSPIRE Directive (2007/2/EC)**, particularly as noted in the preamble, point (24) of Directive 2014/89/EU.

4.2. Visualization Workflow

A visualization workflow can be implemented through a three-layer architecture, as presented in Figure 9.

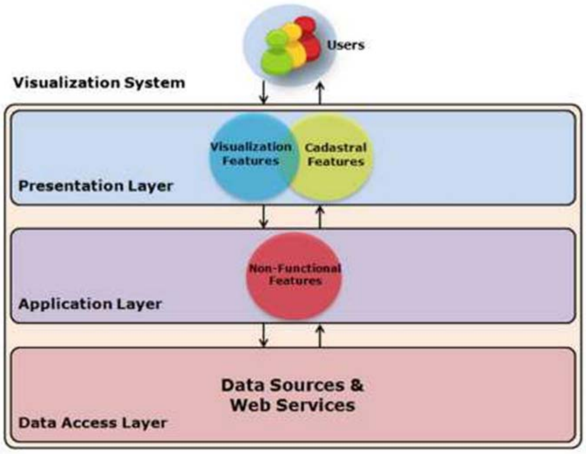

Figure 9. A general architecture for 3D cadastral visualization systems
Source: (Davood Shojaei, Mohsen Kalantari, Ian D. Bishop, Abbas Rajabifard, Ali Aien, 2012)

The three layers of the Visualization System are the following:

1) **Presentation Layer**: This is the front end of the system that interacts with users. It includes two sets of features: cadastral features and visualization features. Cadastral features are critical in representing rights, restrictions, and responsibilities effectively in cadastral applications. The absence of these features would significantly limit the effectiveness of a 3D cadastral visualization system. Visualization features facilitate effective communication between users and the system and may overlap with cadastral features.
2) **Application Layer**: This layer includes non-functional features that support technical diversity, system interoperability, integration, and usability. Although these features do not directly relate to visualization, they indirectly impact the quality and effectiveness of the visualization.
3) **Data Access Layer**: This layer provides data accessibility, including format translation, and connects to spatial databases, flat files, and web services. It ensures that data is available for use by the presentation and application layers.

5. Conclusion and Perspectives

The sustainable development of the Blue Economy depends on effective marine governance that strikes a balance between protecting ecological integrity and promoting economic growth. This analysis has delved into the technical aspects of spatial data preparation within Marine Administration Systems, emphasizing the critical role of advanced data models, adherence to international standards, and the use of innovative visualization techniques.

Several important observations emerge from the analysis:

1) **Significance of Marine Administration Systems**
Marine Administration Systems are increasingly vital as pressures on marine resources grow due to climate change, population increases, and economic demands. These systems play a key role in managing marine spaces, delineating rights and responsibilities, and ensuring resources are used sustainably and fairly.
2) **Role of UNCLOS Framework**
The United Nations Convention on the Law of the Sea (UNCLOS) provides the essential legal foundation for defining marine boundaries and rights. Integrating this framework into national policies is crucial for ensuring compliance and enabling effective governance of marine resources.
3) **Advantage of 3D/4D Data Models**
The complexity of marine environments requires the adoption of 3D and 4D data models to accurately represent marine parcels. This approach enhances spatial understanding and helps manage the overlapping rights and responsibilities of different stakeholders.
4) **Importance of International Standards for Interoperability**
Following international standards like LADM, S-100, and INSPIRE is essential for ensuring interoperability and data consistency across borders. This is especially important for managing shared marine resources and addressing transboundary marine issues.

Based on these insights, several actions could significantly improve the effectiveness of Marine Administration Systems:

1) **Prioritize Investment in Data Infrastructure**
Adequate investment in marine data infrastructure is critical. Governments should allocate sufficient resources to develop spatial data systems that enable efficient data collection, management, and sharing.

2) **Focus on Capacity Building**
Establish training programs to enhance the technical skills of marine administration professionals. This ensures stakeholders are well-equipped to use advanced technologies and data models effectively.
3) **Foster Collaborative Approaches**
Encouraging collaboration among various stakeholders—including governments, private sector actors, and local communities—can improve marine spatial planning. Multi-stakeholder engagement ensures diverse perspectives are considered, promoting transparency and shared responsibility.
4) **Support Research and Innovation**
Encouraging research and innovation in marine data collection, analysis, and visualization is essential. Exploring new technologies and methodologies can lead to better decision-making and improved management of marine resources.

Integrating robust spatial data systems into Marine Administration is essential for promoting the sustainable development of the Blue Economy. By focusing on investment, collaboration, and innovation, these systems can help balance ecological needs with economic growth effectively.

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7. Biographical Notes

Neculai Avramiuc is currently employed as a Cadaster Counselor at the National Agency for Cadaster and Land Registration. He has previously held the position of Head of the Geodesy and Research & Development Department at the National Center for Cartography, where he was responsible for the project ‘Determination of a New Gravimetric Quasigeoid for Romania.’ He is also the author of *TransDatRO*, the national official coordinate transformation software.

Claudia-Mădălina Brebeuță is currently employed as a Cadaster Counselor at the National Agency for Cadaster and Land Registration. From 2013 to 2023, she served as the Head of the Approvals and Receptions Office at OCPI Ilfov, where she actively participated in the implementation of cadastre regulations at the territorial office level and contributed to legislative changes during that period by making relevant proposals. From 1994 to 1999, she worked as a scientific researcher in cartography at the current Defense Geospatial Information Agency, "Division General Constantin Barozzi."

Stela Bălan is currently employed as a Cadaster Counselor at the National Agency for Cadaster and Land Registration, having been involved in various projects. From 2005 to 2008, she participated in the registration of state-owned lands managed by the State Domain Agency in the land registry. Subsequently, as an employee of the territorial office, she was involved in systematic cadastre activities and handled cadastral documentation submissions.